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TITLE: THE INITIAL INCREASE, "PEAKING EFFECT", IN THE INTERNAL FRICTION OF COPPER FOLLOWING PULSED NEUTRON AND ELECTRON IRRADIATION

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The Initial Increase, "Peaking Effect", in the Internal Friction of Copper Following Pulsed Neutron and Electron Irradiation

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Résumé - Under certain experimental conditions the internal friction in metals can first increase and following prolonged irradiation decrease. Many models have been proposed to account for this "peaking effect"; however, in many of the cases, no effort is made to distinguish between the influence of interstitials and/or vacancies. To determine the nature of the point defect responsible for the peaking effect in high purity copper, we have performed a series of pulsed irradiations using neutrons and electrons. In all of the experiments an initial very rapid rise in the internal friction and Young's modulus was observed. These data show that a fast diffusing defect is responsible for the peaking effect: i.e. the interstitial.

Abstract - Under certain experimental conditions the internal friction in metals can first increase and following prolonged irradiation decrease. Many models have been proposed to account for this "peaking effect"; however, in many of the cases, no effort is made to distinguish between the influence of interstitials and/or vacancies. To determine the nature of the point defect responsible for the peaking effect in high purity copper, we have performed a series of pulsed irradiations using neutrons and electrons. In all of the experiments an initial very rapid rise in the internal friction and Young's modulus was observed. These data show that a fast diffusing defect is responsible for the peaking effect: i.e. the interstitial.

I - INTRODUCTION

Early experiments on the effects of irradiation on the internal friction in metals /1/ were interpreted on the basis of the vibrating string model proposed by Koehler /2/ and extended by Granato and Lucke /3/. In this model radiation produced defects created in the lattice migrate to and firmly anchor (pin) the dislocations at random points. This leads to a shortening of the average dislocation length with a corresponding decrease in the damping and an increase in the modulus. Numerous experimental results have been explained using this model with varying degrees of success. This picture had to be modified in 1971 when Simpson and Sosin /4,5/ showed that under special experimental conditions, the internal friction first increased dramatically at the onset of irradiation and following prolonged irradiation the damping decreased to well below its pre-irradiation value. Such behavior has been named the "Peaking Effect" (PE). The modulus increased monotonically during the irradiation. Following this preliminary work, PE has been observed in numerous metals and under various experimental conditions /6-17/. The important aspects of the PE have recently been summarized by Minier et al. /18/ and by Feltham /19/. None of these models have been entirely successful in describing PE. Separation of the effects due to interstitials and vacancies during irradiation has been a major obstacle in understanding PE. Simpson and Kerkhoff /15,20/ were able to show that vacancies can only pin dislocations implying that PE is due to the interaction of interstitials with dislocations. Pulse irradiations have also been conducted /16,21-24/, however the long pulse duration (tens of seconds to an hour) has hampered separation of defect effects.

To unravel the nature of the defect that causes PE during irradiation, we performed a series of pulsed neutron (40μsec) and electron (0.4 second, 1 MeV) irradiations on a copper sample over a temperature span form 310 to 430 K. In addition the flux dependence was examined. Results are interpreted in light of the current models of PE.

II - EXPERIMENTAL PROCEDURE AND RESULTS

Experimental details are similar to our previous work /13,25/. The pulsed neutron experiments were using a fast-burst assembly which produces a fission-like spectrum of about 40μsec duration leading to a fluence of 10^{18} n/m^2. Electron irradiations were performed using 1.0 MeV electrons in 0.4 second pulses generated by a mechanical shutter Table 1 lists the fluences for the constant temperature data. The PE for this sample was characterized by performing a continuous electron irradiation at 370K. A well defined peak is observed with a height of 1.4 and a modulus defect of 4.5% is exhibited. This behavior is typical of thct shown by most experimenters.

A series of pulsed irradictions at 370K were performed with a variation in fluence of about a factor of ten. A very rapid rise in the decrement occurs during the first tens of seconds with little change occurring after the first couple hundreds of seconds (see figure 1a). Electron irradiations produce ten times the number of defects as neutron irradiations, thereby producing a larger initial increase in the decrement. The maximum value of δ/δ_o scales linearly with dose. A gradual decrease in the damping occurs after the first couple of hundred seconds, this behavior is not the same as the peak produced during continuous irradiation, and therefore will be referred to as an anomalous peak. Modulus measurements recorded simultaneously show a monotonic increase as a function of time (see figure 1b). As with the decrement data, most of the increase occurs in the first tens of seconds. A series of pulsed neutron and electron irradiations at constant dose were performed over the temperature range 310 to 430K. Note the strong temperature dependence of the decrement (figure 2a). Modulus data shown in figure 2b reflects the same general trends as observed for the decrement data, particularly the strong temperature dependence.

III - DISCUSSION

The data for both pulsed electron and neutron irradiations show essentially the same time, dose, and temperature dependent behavior. For all experiments, the data show a very rapid rise (within tens of seconds) of the decrement and modulus, however this response is not instantaneous. A second universal feature is the slow decrease in the decrement and a slow increase in the modulus at long times. This peak in the decrement is not PE since the value of δ/δ_o = 1.4 is not reached even in the case of electron irradiations. For neutron irradiations, the number of defects arriving at dislocations is a factor of hundred less (ten less in fluence and ten less in free defect production per particle). Thus an anomalous peak is observed in the data.

As pointed out in the introduction, there are many models to account for PE. These range from the original dragging model of Simpson and Sosin /4/ with extensions by Ogurtani /26,27/ and Lucke and Granato /28/ to the most recent "hysteretic" model proposed by Feltham /19/. Since all of these models can by proper choice of parameters "fit" a selected set of PE data, the present experiments are interpreted only in terms of the most general features of the models. Be they "hysteretic" or "relaxational", it is of major importance to determine whether the PE is caused by the long range interaction (global effects) of defects with or by action directly on the dislocations. Since the data clearly show that a fast diffusing defect is first created in the good lattice and subsequently migrates to the dislocation, the "global effects" models /16,17,24,29/ can be ruled out since they require an instantaneous PE. The current experiments do not address the question of amplitude, frequency, and sample preparation dependence so that no definitive selection from the remaining models can be made.

One of the most interesting features of the isodose data is the strong temperature dependence of the maximum in the decrement and the modulus defect after the first few hundred seconds. Since the same number of defects were created, one would expect the final values of the decrement and modulus to be temperature independent: i.e. only time dependence should be observed. The observed temperature dependence could be due to (1) complicated diffusion kinetics which allow more defects to reach dislocation at higher temperatures or (2) to the temperature dependence of dislocation parameters. No current model sufficiently addresses these possibilities, such as adding temperature dependence to the dragging model. Clearly additional experiment are needed before this temperature dependence will be fully understood.

IV - CONCLUSIONS

Qualitative analysis of pulsed neutron and electron irradiation shows that the peaking effect is due to the short range interaction of point defects with dislocations as opposed to some long range "global effect". This defect is identified as the fast diffusing interstitial which is created in the good lattice and subsequently diffuses rapidly to the dislocations. Following the depletion of the free interstitials, vacancies slowly diffuse to the dislocations and produce pinning. This leads to a reduction of internal friction. Work supported by the U. S. Department of Energy.

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Table 1
Pulsed Neutron and 1 MeV Electron Irradiations at 370 K

Neutron	Dose (10^{14} n/m)	Electron	Dose (10^{16} e/m)
0n	0	0e	0
1n	1.49	1e	0.95
2n	5.78	2e	3.12
3n	9.58	3e	9.68
4n	15.1	4e	30.8

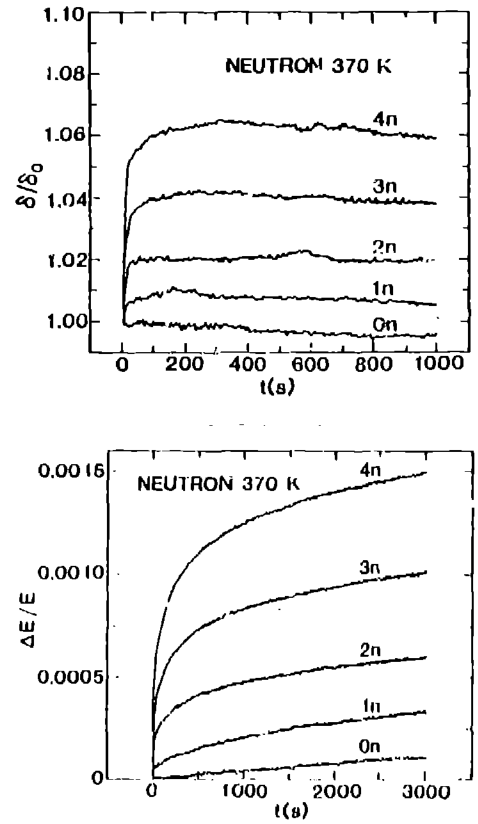

Figure 1: (a) Normalized decrement neutron irradiations listed in table I. (b) Modulus change corresponding in data in figure a.

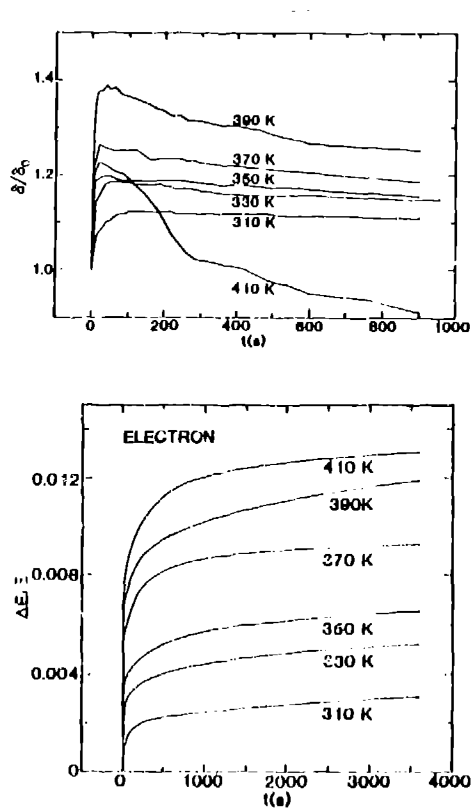

Figure 2: (a) Normalized data for data decrement data for electron irradiations from 310 to 410 K. (b) Modulus change corresponding to data in figure a.